Applied Ergonomics 130 (2026) 104637

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

The physiological demands of a military dismounted assault task☆

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ARTICLE INFO

Keywords:
Combat effectiveness
Military performance
Aerobic fitness

ABSTRACT

Aim: Characterise the physiological demands of a military dismounted assault task (DAT) simulation. Method: Fourteen men (mean ± SD: age 29 ± 9 years; body mass 79.9 ± 9.2 kg; $\dot{V}O_{2peak}$ 51.9 ± 4.4 ml·kg^{-1}·min^{-1}; upright pull strength 177 ± 20 kg) performed a DAT (external load 24.3 kg) of 16 × 6 m bounds in 20 s cycles (5 s work, 15 s rest) followed by an 18 m leopard crawl. Performance and physiological demands (heart rate and indirect calorimetry via the Douglas bag technique) during the first and last 48 m of bounds and the leopard crawl were compared using a one-way repeated measures ANOVA. Performance was maintained across the first and last 48 m (bound speed 5.7 ± 0.9 and 5.8 ± 0.8 km·h^{-1}) despite substantial increases in oxygen consumption (first 48 m 25.4 ± 3.3 ml·kg^{-1}·min^{-1}; last 48 m 31.7 ± 3.5 ml·kg^{-1}·min^{-1}; leopard crawl 40.4 ± 6.4 ml·kg^{-1}·min^{-1}, $p < 0.001$, $\omega^2 = 0.64$). Mean leopard crawl time was 26.1 ± 8.1 s at a speed of 2.7 ± 0.8 km·h^{-1} and post-exercise blood lactate was 3.8 ± 1.4 mmol·L^{-1}. Increasing oxygen consumption with modest blood lactate responses suggests the demands of the DAT simulation are similar to intermittent high-intensity exercise and that aerobic fitness is an important determinant of performance.

1. Introduction

High-intensity tactical movements have been identified as a critical task for those involved in military job roles (Stein et al., 2021). They are frequently rated as one of the most physically demanding soldiering tasks due to the combined demands of aerobic endurance, anaerobic endurance and muscular strength (Doyle et al., 2012; Larsson et al., 2020; Sharp et al., 2017). Whilst much research to date has examined the physical cost of low intensity exercise carrying external load, the ability to conduct high-intensity intermittent exercise carrying load is comparatively less well researched (Faghy et al., 2022). Such tasks include break contact drills, allowing soldiers to withdraw under fire, and offensive assault tasks.

The Australian defence force devised a dismounted assault task (DAT) simulation based on approach distances and staged in-field observations of soldiers completing this task (Silk and Billing, 2013). Davidson et al. (2021) used an inertial measurement unit to quantify the demand of the DAT simulation across three phases: get up time, sprint time, get down time. Both the time to rise and adopt the prone firing position significantly discriminated between high and low performers, with low performers demonstrating an increased exposure time during movement bounds that results in an increase in susceptibility to enemy fire (Blount et al., 2013). Susceptibility during a DAT simulation has further been demonstrated to increase when conducting movements with external load, but is subject to high interindividual variability (Billing et al., 2015; Hunt et al., 2016). Whilst Billing et al. (2015) found susceptibility was not related to physical qualities, arguing that task experience is key, Canino et al. (2019) demonstrated no difference in performance (i.e., movement time or velocity) during a staged assault task between trainees and active soldiers. This suggests variability in risk arises at least in part due to individual physical capability, rather than task experience.

Accordingly, research has found relationships between task performance, anthropometrics, and components of physical fitness, which collectively minimise susceptibility (Foulis et al., 2015; Hoffman et al., 2016; Hunt et al., 2016; Stein et al., 2022, 2023). Observed bound speed reported from combat simulations of ~2 m·s^{-1}/7 km·h^{-1} (Larsson et al., 2020; Silk and Billing, 2013) are relatively modest, but it has been reported that both critical speed and multistage fitness test performance predict high-intensity tactical task performance (Foulis et al., 2015; Hoffman et al., 2016; Pihlainen et al., 2018; Stein et al., 2022). Critical speed has been described as the asymptote of the curvilinear

☆ Ethical approval was granted by the University of Chichester Research Ethics Committee (protocol number 1718_05) and the research was conducted in accordance with the principles of the World Medical Association's Declaration of Helsinki.

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https://doi.org/10.1016/j.apergo.2025.104637
Received 24 March 2025; Received in revised form 28 July 2025; Accepted 2 September 2025
Available online 18 September 2025

relationship between sustainable speed and time (Jones and Vanhatalo, 2017), and has previously been advocated for military performance assessments (Fukuda et al., 2012). Further, others have noted that capacity above critical power (i.e., substantially anaerobic energetic contributions), assessed via expedient field test, are not correlated with high-intensity intermittent tasks (Beck et al., 2014; Hoffman et al., 2016). This indicates that the demands of the DAT simulation are akin to high-intensity intermittent exercise near critical speed. Intensity would be expected to be of the 'severe' domain, whereby oxygen consumption ($\dot{V}O_2$) and associated metabolism would not exhibit steady state behaviour (Jones and Vanhatalo, 2017). However, the relative energy contributions may be influenced by the overall duration of exercise, duration of work to rest ratios, and training status of an individual (Glaister, 2005). Whilst others have attempted characterisation of a DAT simulation using heart rate and GPS during field activities (Larsson et al., 2022; Pihlainen et al., 2018), no research has quantified the physiological demand of a DAT simulation using indirect calorimetry. To avoid decrements in operational effectiveness, valid characterisation of the physiological load of high-intensity tactical movements is necessary to inform performance and training targets.

2. Methods

2.1. Participants

Fourteen non-military men, who displayed similar physical fitness to previous military research (Larsson et al., 2022; Stein et al., 2022), volunteered for the study (mean ± SD: age 29 ± 9 years; height 181.2 ± 5.7 cm; body mass (BM) 79.9 ± 9.2 kg; $\dot{V}O_{2peak}$ 51.9 ± 4.4 ml·kg^{-1}·min^{-1}, 4.12 ± 0.38 L·min^{-1}; upright pull strength 177 ± 20 kg). Participants were healthy, active and injury free as confirmed by a medical questionnaire. Following a verbal debrief of the study protocols, written informed consent was obtained from all participants. Ethical approval was granted by the Research Ethics Committee of the University of Chichester and the research was conducted in accordance with the principles of the World Medical Association's Declaration of Helsinki.

2.2. Study design

Participants completed three test sessions separated by 5–7 days. The first visit consisted of an incremental treadmill determination of $\dot{V}O_{2peak}$ and assessment of upright pull strength. Participants were then familiarised with the DAT protocol, before physiological demands of the DAT simulation were assessed in a separate session at least 48 h post familiarisation.

2.3. Maximal oxygen consumption and upright pull strength assessment

Upon arrival to the laboratory, height and body mass were measured to the nearest 0.1 cm and 0.1 kg, respectively (Seca 213 Portable stadiometer; Seca Scales Model 873; Seca Medical Measuring Systems & Scales, Birmingham UK). In a temperature-controlled thermoneutral laboratory (19 °C), $\dot{V}O_{2peak}$ was assessed through a ramp-protocol on a motorised treadmill with a 1 % incline (Woodway Ergometer ELG 70, Cranlea & Co. Bourneville, Birmingham, UK). Treadmill speed was increased by 0.25 km·h^{-1} per 15 s until volitional exhaustion, with all tests completed within 12 min. Indirect calorimetry variables (O_2 uptake, CO_2 production, and minute ventilation) were determined during each 60 s stage using a 200 L Douglas Bag (Servomex; Crowborough, East Sussex, UK; Harvard Dry Gas Meter, Havard Apparatus, Edenbridge, Kent, UK). Heart rate (HR) was recorded throughout (Polar Consultancy RS800; Polar Electro UK Ltd. Warwick, UK) with maximal heart rate (HR_{max}) defined as the highest 10 s moving average.

Isometric strength was measured through a 38 cm upright pull in line with previous measures of the same nature (Knapik et al., 1981; Rayson et al., 2000). Using an overhand grip with bent knees, participants performed three maximal efforts interspersed by 2 min of recovery with the highest repetition reported (Back and Leg Dynamometer, Takei Scientific Instruments).

2.4. Dismounted assault task

The DAT simulation was conducted on an indoor, level surface in an ambient temperature of 25.3 °C ± 3.8 °C in accordance with the simulation devised by Silk and Billing (2013). The simulation has two major components: an approach of 16 × 6 m bounds and an 18 m leopard crawl (LC). A course was set up over 24 m (4 × 6 m bounds, Fig. 1) and repeated four times before the LC. In accordance with previously determined mean fighting order load (Silk and Billing, 2013), participants carried a functionally equivalent mean external load of 24.3 kg, comprising of a 15 kg weighted vest (RDX Inc.; Bury, UK), a ~5 kg (~3 kg lead shot and ~2L of water) Camelbak (CamelBak Products, LLC; Petaluma, CA) and a ~4 kg simulated rifle. Participants were fitted with a HR monitor (Polar Consultancy RS800; Polar Electro UK Ltd. Warwick, UK), whole-body coveralls, and knee pads for safety.

Bounds were performed on a 20 s cycle; each sprint was completed within 5 s with a 15 s rest period between each bound. Starting from a prone firing position, participants were instructed to sprint between cones and adopt a one knee firing position at each 6 m interval before returning to a prone position after 5 s via an audible 'beep'. Participants were instructed to complete each bound as quickly as possible and not to pace themselves. For standardisation, if participants completed a bound faster than 5 s, they were instructed to remain on one knee and wait for the beep before returning to the prone position. Following completion of the 16 bounds, participants were afforded a further 15 s rest before commencement of the LC. Participants were again instructed to complete the LC as quickly as possible and to keep as low as possible, with verbal feedback on body position and encouragement provided throughout. Time remaining, or in excess, of a 35 s target time was recorded.

Expired gas, using the Douglas bag technique, and HR (Polar Vantage, Polar, Finland) was collected continuously throughout the test. Three 200 L Douglas bags were used allowing assessment across three phases: the first 48 m, the last 48 m (both approximately 160 s), and the leopard crawl. Douglas bags were affixed to a wheeled rack and connected to participants via a breathing tube with enough length to ensure ease of movement. Expired air was collected by an experimenter manually keeping pace with participants. Indirect calorimetry variables (O_2 uptake, CO_2 production, and minute ventilation) were determined as the average values across these stages (Servomex, Crowborough, East Sussex, UK; Harvard Dry Gas Meter, Havard Apparatus, Edenbridge, Kent, UK). Fingertip-capillary blood lactate (BLa) was sampled 3-min post completion of the LC and immediately analysed (YSI 2300 STAT PLUS, Analytical Technologies, Farnborough, UK). Data are expressed as both absolute consumption values and relative to individual body mass (excluding external load). Mean bound speed across the first and last 48 m and LC speed was determined using Quintic video analysis (Quintic Biomechanics version 26, Quintic Consultancy Ltd), where bound time

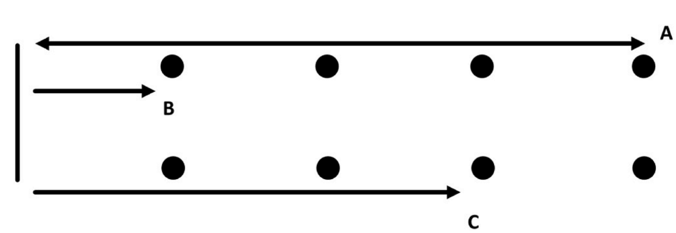

Fig. 1. Set up of the dismounted assault task. A) 24 m course comprising B) 6 m bounds. C) 18 m leopard crawl distance.

was defined from the frame in which participants began to push up from the floor to the frame in which their knee came into contact with the floor. Susceptibility to enemy fire was determined using the formula: $1-(1-[\text{accuracy}])^{((\text{bound time in s}-[\text{reaction time}])\times[\text{firing cadence}])}$, where accuracy is set to 10 %, reaction time is set to 1 s, and firing cadence is set to 1.3 (Blount et al., 2013; Stein et al., 2022).

2.5. Statistics

All analyses were performed in JASP (JASP Team (2022). JASP (Version 0.16.4) [Computer software]). Following normality tests, physiological differences between the first 48 m, last 48 m, and LC were assessed using a one-way repeated measures ANOVA, with Greenhouse-Geisser correction where required. Effect sizes are presented as Omega squared (ω2) (Levine and Hullett, 2002). Post hoc exploration of significant main effects was performed using a Holm correction to control for multiplicity. Bound speed between the first and last 48 m was compared through a paired *t*-test. Statistical significance was set a-priori at 0.05.

3. Results

A summary of the physiological demands of the DAT simulation are presented in Table 1 with results indicating a significant rise in physical demand across the three phases. Relative oxygen consumption increased with each phase, rising from 49.0 ± 5.3 % of $\dot{V}O_{2peak}$ in the first 48 m to 61.1 ± 5.5 % in the last 48 m and 78.2 ± 12.1 % during the LC (Fig. 2). Similarly, mean HR increased throughout, rising from 71 ± 7 % of HR_{max} in the first 48 m to 80 ± 7 % and 87 ± 7 % during last 48 m and LC, respectively. Post LC BLa was 3.8 ± 1.4 mmol·L^{-1} (range: 1.6–6.0 mmol·L^{-1}).

There was a small, statistically significant, increase in mean bound speed during the last 48 m compared with the first 48 m of the DAT simulation ($t_{(12)} = 2.269$, $p = 0.043$, $d = 0.629$; Fig. 3), with participants averaging 5.7 ± 0.9 and 5.8 ± 0.8 km·h^{-1}, respectively. This was accompanied by a small reduction in bound time (3.8 ± 0.6 and 3.7 ± 0.6 s) and susceptibility to enemy fire (32 ± 5 and 31 ± 5 %). The mean leopard crawl time was 26.1 ± 8.1 s at a speed of 2.7 ± 0.8 km·h^{-1}; one participant failed to complete in the target time of 35 s (43.4 s).

4. Discussion

This is the first study to quantify the physiological demand of a DAT simulation through combined measurements of indirect calorimetry, HR, and BLa. These data provide additional insight into the physical demands of the DAT simulation previously quantified through heart rate and GPS estimates (Larsson et al., 2022; Pihlainen et al., 2018). Speculatively, the moderate $\dot{V}O_2$ in the first 48 m of work suggests an ability

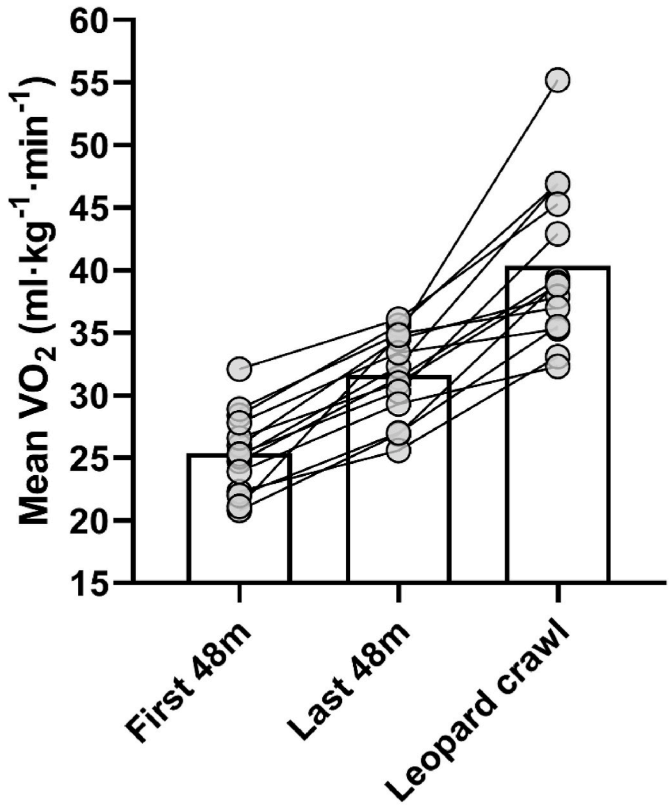

Fig. 2. Mean oxygen uptake during the dismounted assault task.

to meet task demand through intramuscular adenosine triphosphate and phosphocreatine (PCr) stores. However, in the latter 48 m there was a significant rise in oxygen consumption, likely mediated by a rise in adenosine diphosphate (ADP) and inorganic phosphates, coupled with a reduction in PCr availability (Glaister, 2005). This assumption is supported by the known half-time of the fast-component recovery kinetics of PCr, reportedly 21–22 s (Harris et al., 1976), which is longer than the 15 s recovery time afforded here. The rise in oxygen consumption, progressing towards $\dot{V}O_{2peak}$ in the leopard crawl, is consistent with the increased contribution of oxidative metabolism expected from repeated sprint work (Girard et al., 2011). Indeed, the mean $\dot{V}O_2$ and HR achieved by the end of the 16 bounds are typical of values recorded in intermittent sports (Glaister, 2005). Importantly, the measured intensity was sufficient to maintain adequate performance throughout. This is demonstrated by a lack of reduction in movement speed or increased susceptibility to enemy fire, which was comparable to previous studies under similar conditions (Billing et al., 2015; Stein et al., 2022). In

Table 1
Physiological demands of the DAT simulation. Data are mean ± SD. Post hoc results presented in relation to immediately previous DAT phase.

	First 48 m	Last 48 m	Leopard crawl	Main effects
$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	25.4 ± 3.3	31.7 ± 3.5 $t_{(13)} = 4.49$, $p < 0.001$, $d = 1.37$	40.4 ± 6.4 $t_{(13)} = 6.24$, $p < 0.001$, $d = 1.91$	$F_{(14.62,1.13)} = 58.00$, $p < 0.001$, ω2 = 0.64
$\dot{V}O_2$ (L·min^{-1})	2.03 ± 0.27	2.53 ± 0.22 $t_{(13)} = 4.89$, $p < 0.001$, $d = 1.49$	3.23 ± 0.46 $t_{(13)} = 6.89$, $p < 0.001$, $d = 2.10$	$F_{(14.53,1.12)} = 70.05$, $p < 0.001$, $\omega^2 = 0.68$
$\dot{V}CO_2$ (L·min^{-1})	1.62 ± 0.27	2.24 ± 0.33 $t_{(13)} = 6.72$, $p < 0.001$, $d = 1.48$	3.00 ± 0.59 $t_{(13)} = 8.21$, $p < 0.001$, $d = 1.81$	$F_{(14.54,1.12)} = 111.86$, $p < 0.001$, $\omega^2 = 0.64$
RER	0.80 ± 0.11	0.88 ± 0.08 $t_{(13)} = 4.23$, $p < 0.001$, $d = 0.89$	0.93 ± 0.08 $t_{(13)} = 2.11$, p 0.045, $d = 0.44$	$F_{(14.91,1.15)} = 20.84$, $p < 0.001$, $\omega^2 = 0.23$
$\dot{V}_E$ (L·min^{-1})	51.8 ± 9.5	69.1 ± 11.7 $t_{(13)} = 5.35$, $p < 0.001$, $d = 1.16$	104.9 ± 20.9 $t_{(13)} = 11.10$, $p < 0.001$, $d = 2.40$	$F_{(14.57,1.12)} = 140.78$, $p < 0.001$, $\omega^2 = 0.69$
Max HR (b·min^{-1})	145 ± 17	154 ± 15 $t_{(12)} = 5.68$, $p < 0.001$, $d = 0.64$	167 ± 14 $t_{(12)} = 7.21$, $p < 0.001$, $d = 0.81$	$F_{(24,2)} = 83.56$, $p < 0.001$, $\omega^2 = 0.26$
Mean HR (b·min^{-1})	131 ± 15	147 ± 17 $t_{(12)} = 7.07$, $p < 0.001$, $d = 0.99$	161 ± 17 $t_{(12)} = 5.52$, $p < 0.001$, $d = 0.77$	$F_{(15.65,1.30)} = 79.61$, $p < 0.001$, $\omega^2 = 0.34$

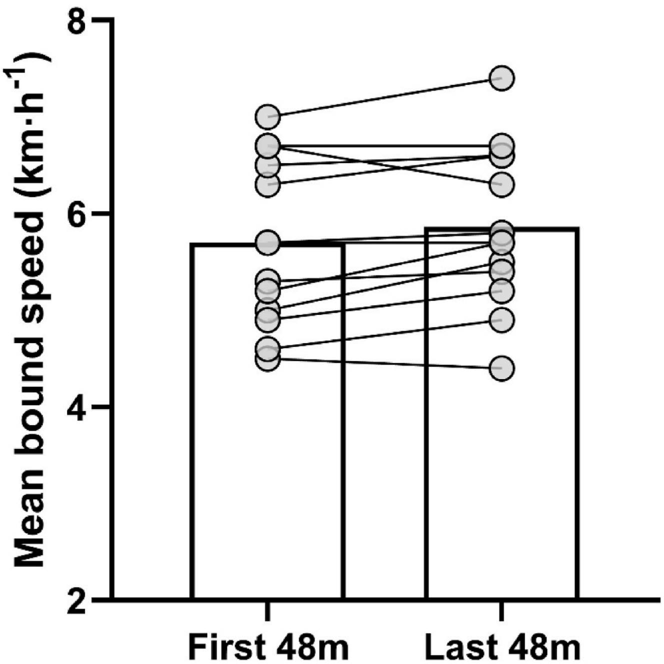

Fig. 3. Mean bound speed during the dismounted assault task.

addition, the present study did not observe maximal intensity values for oxygen consumption, HR, or BLa. Therefore, for the majority of participants, the results suggest non-steady state exercise in the severe intensity domain (Jones and Vanhatalo, 2017), but not an exhaustive anaerobic demand. This is consistent with previous association research which has observed that high-intensity tactical task performance is correlated to aerobic capacity (Foulis et al., 2015; Pihlainen et al., 2018) and critical speed (Fukuda et al., 2012; Hoffman et al., 2016; Stein et al., 2022), but not specific anaerobic qualities (Beck et al., 2014; Hoffman et al., 2016).

However, some inter-individual variability was observed. This was most apparent during the leopard crawl, where some participants approached maximal intensity and one failed to complete within the target time. This suggests a varying anaerobic demand amongst participants, despite previous work suggesting anaerobic capacity does not predict repeated sprint performance in military tasks (Beck et al., 2014; Hoffman et al., 2016). During high-intensity intermittent work, anaerobic energy contribution is partly driven by the recovery kinetics of phosphocreatine stores, calcium handling, and metabolite accumulation, leading to inter-individual variability in aerobic energy provision (Balsom et al., 1992). It is acknowledged that the use of the Douglas bag technique makes determination of anaerobic requirements difficult, such as the demand and volume of active muscle mass, and contribution of myoglobin (Glaister, 2005). Regardless, it is well established that PCr recovery and ADP resynthesis are related to aerobic capacity (Balsom et al., 1992; Kemp et al., 1993), so these data support previous recommendations to improve aerobic fitness as a means to support recovery during high-intensity intermittent exercise (Glaister, 2005; Hoffman et al., 2016).

Variability in demand is likely further explained by load carriage requirements, which represented a mean load of ~30 % of participants body mass. A break contact drill simulation devised by Laing Treloar and Billing (2011) of 5 × 30 m sprints at 44 s intervals demonstrated a 31.5 % increase in sprint time with the addition of an external load of 21.6 kg compared to completing the simulation unloaded. When comparing both the break contact drill and DAT simulations, both susceptibility and performance (i.e., movement velocity) have been shown to be a function of external load (Billing et al., 2015; Hunt et al., 2016). Although of a comparable fitness standard to past military research (Billing et al., 2015; Hoffman et al., 2016; Larsson et al., 2022; Stein et al., 2022), a convenience sample was used in the present study which may not be representative of all possible service personnel. Billing et al. (2015) found that physical and physiological qualities (e.g., upper and lower body power, and estimated aerobic capacity) could not explain inter-individual variability in susceptibility, potentially highlighting the importance of training tactical movements. Further, the present study is also limited by a lack of women in the sample. It has been demonstrated that the physiological and biomechanical demand is higher for women during load carriage at intensities >5.5. km·h^{-1}, albeit not during a DAT simulation (Vickery-Howe et al., 2024).

However, Stein et al. (2023) report that anthropometrics and body composition influence high-intensity tactical task performance when controlling for sex, whilst others have reported that dead mass, body mass minus external load and fat mass (Pihlainen et al., 2018; Stein et al., 2023), and greater lower body power (Hunt et al., 2016; Stein et al., 2022) are strong predictors of performance and reduced susceptibility. Therefore, whilst sex per se may not influence DAT performance, reproducing these results with a wider range of anthropometric and physical performance capabilities is warranted. Specifically, Davidson et al. (2021) found the strongest correlate of performance during a similar assault task to be prone get down time, as opposed to get up time or sprint time, which suggests specific deceleration qualities may also be of interest for future research. Conversely, others have found that susceptibility was highest at the onset of movement, which may reflect upper body qualities when rising from prone or accelerating (Billing et al., 2015; Hunt et al., 2016). Research to date has only explored relationships with the DAT simulation using expedient field tests and limited sample sizes. To elucidate the relative importance of performance predictors, future research should explore more precise physiological and biomechanical measures, such as critical speed and ground reaction forces, in both men and women with sufficiently representative physical, physiological, and anthropometric characteristics. It should also be stressed that susceptibility, as devised by Blount et al. (2013), is an approximation; future research may also wish to explore factors influencing risk, such as fatigue, and opportunities for countermeasures, such as nutritional interventions.

In conclusion, the present study characterises the physiological demands of performing high-intensity tactical movements during a DAT simulation. The physiological demands are similar to high-intensity intermittent movements reported in sporting literature indicating non-steady state oxygen uptake, but not an exhaustive anaerobic demand. Importantly, these findings suggest that aerobic fitness is an important determinant of performance and reduced susceptibility during intermittent high-intensity load carriage tasks.

CRediT authorship contribution statement

Stephen J. McGuire: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Sam D. Blacker:** Writing – review & editing, Methodology, Conceptualization, Supervision. **David M. Wilkinson:** Supervision, Methodology, Conceptualization. **Stephen D. Myers:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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